Analysis of elemental concentrations of biologically important elements in caprine milk and commercial caprine milk replacers using instrumental neutron activation analysis

Alyssa Larue

Research Advisor: Joseph Talnagi

Advisor: Dr. Michael Day

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Abstract

Goats play an important role in meat and milk production around the world. Goats are especially important to underdeveloped countries due to their ability to live in harsh climates where other livestock animals cannot survive. Baby goats that are fed commercial milk replacer seem to be less robust than goats fed natural goat milk. The objective of this study was to determine if differences in mineral concentrations that could be affecting the animal's health exist between these milk sources. Goat milk was collected from 44 does at the start of lactation and towards the end of lactation. Ten does were collected a second year to determine environmental influences between years that might influence milk composition. My hypothesis is that commercial milk replacer will be either deficient or excessive in elements that have been previously demonstrated to impact health of neonates. Instrumental neutron activation analysis was used to identify Mg, Mn, Na, Cl, Al, Br, and K. This process coverts the natural elements into isotopes, which are then quantified by gamma ray spectrometry using standards with known elemental concentrations that were also irradiated. This approach can detect differences in ppm in mineral content. Results show that, in a comparison of season, only chlorine is differs. Milk from individual goats does not vary in mineral content within the herd. Within the same season, bromine and magnesium were lower in concentration in early than late lactation. Among the different milk replacers studied in this research, potassium, sodium and aluminum concentration differed between sources. Several elements were found to differ when comparing the different types of water. The final comparison studied found that sodium and aluminum concentrations are lower when comparing natural goat milk than milk replacer concentration. Several of these differences suggest that care must be taken to insure that the young get the correct mixture according to their stage of lactation.

Objective

On our farm, where we have an eighty head goat flock, it has always been noted that bottle babies have poor growth and are less healthy than goats getting their mother's milk. A study to compare commercial caprine milk and caprine milk for elemental (mineral) content would be useful to determine differences that would lead to the poor overall health of bottle babies. After talking with a lactation expert at OSU Wooster (Bill Weiss), we determined which elements are essential, probably essential, and toxic to young goats. The elements that are considered essential for baby goats are sodium, magnesium, chlorine, potassium, chromium, calcium, manganese, iron, cobalt, copper, zinc, and iodine. Elements that are probably required are vanadium and nickel. Four elements that may be needed in minute amounts, but can be toxic in excess are aluminum, arsenic, molybdenum and mercury. Some of these elements produce isotopes when exposed to nuclear radiation. Not all elements will produce an isotope and some that do produce an isotope have such a short half-life that their presence cannot be detected. However, most of the elements of interest in this study are good candidates for this method of detection. The procedure is extremely accurate, counting elemental content to parts per million (ppm).

Hypothesis

Alternative Hypothesis: There is a difference in mineral content between the commercial milk replacer and natural goat milk.

Null Hypothesis: There is no difference in mineral content between commercial milk replacer and natural goat milk.

Introduction

Goats and milk production

There are around 502 million goats in the world with greater than 90 percent located in underdeveloped countries (Smith, 1994). Goats are very useful due to their ability to adapt to harsh environments where other livestock cannot thrive. Meat and milk production are very important to those in underdeveloped areas; where as, in the United States, milk production from goats is recently a rapidly growing segment of animal agriculture. Nubian goats are the most popular breed with Sannen the second most in the United States (Belanger, 2001). Goats are seasonal polyestrous, meaning their reproductive stages are triggered by decreasing day length in both does and bucks (Smith, 1994). Estrous cycles are about 19-21 days in length (Shelton, 1978).

Milk production in the lactating goat is determined by the number of secretory cells. Before parturition, the secretory cell is undeveloped, but under hormonal control, it differentiates (Tucker, 1981). If too much milk is present and not all is stripped from the udder, the excess is reabsorbed resulting in lower milk production. Oxytocin is a hormone that signals the ‘let-down reflex’ and prolactin is necessary for milk production (Tucker, 1981). A decline in secretory cells signals the dry-off period essential for the animal. Secretory cells increase during pregnancy and after birth until the third week (Wilde, 1989). Maintenance of lactation is signaled by regular milking.

The traditional lactation period of a goat is about 305 days (Belanger, 2001). The goat lactation curve rises rapidly after the birth of young, stays constant before declining as the young matures (Larson, 1978). Does that have babies early in the season generally have better milk production (Shelton, 1978). Goat milk is similar to cow milk with around 87 percent water, 67 percent energy, 3.3 percent protein, 4.0 percent fat, and 4.6 percent carbohydrates (Belanger, 2001). Goat milk differs from cow and human milk in several ways, among them higher digestibility and lower lactose (Larson, 1978). One difference is that goat milk has smaller fat globules present due to the lack of the enzyme that aggregates the globules in the milk (Belanger, 2001). For these reasons, goat milk may be used for human babies that cannot digest human milk. Nutrient content of goat milk differs by breed, diet, stage of lactation, and management. Commercial milk replacers would vary by processing, ingredients, and methods of preparation.

The udder of a goat has two glands into which six to nine milk ducts gland empty and each gland has one teat (Smith, 1994). Some abnormalities may be present with more than one teat on each gland. These extra teats can be easily removed at birth. Several udder conditions play a role in affecting milk production. Among these are cuts, bruising, lumps in the udder and mastitis (an inflammation of the udder); (Hetherington, 2002). A goat mammary gland produces a slow continuous volume of milk. Epithelial cells add fat, protein, and carbohydrates to the watery mixture making the nutrients available to the young. Milk is electrically positive compared to the cells, so sodium and potassium are lower in the milk. Chloride is higher in the mammary cell, perhaps due to Chloride pumps providing channels to regulate the pH of the tissues (Shennan, 2002). The synthesis and secretion of lactose and ion concentrations causes water to enter the milk (Shennan, 2002). Goats are typically weaned when they weigh several times their birth weight. At this time, they change from a partial milk diet to one completely of concentrates (grains) and forages. The does are able to start to stop production of milk at this time.

Mineral nutrition

Minerals are vital to the health of the adult goat and the newborns. Food intake of the mother and how the minerals pass into the milk will determine the mineral content provided to the babies. Minerals compose the ash or inorganic part of the animal's feeds. Most minerals function as cofactors helping to facilitate enzyme reactions. A balance of minerals is extremely important as toxicities and deficiencies are present in most minerals. Another concern is that increasing one mineral can hamper the absorption of another mineral creating a deficiency.

Magnesium is incorporated to an animal's diet by forage consumption. It is stored in the bone (about 70 percent) and about 30 percent in the soft tissues and blood (Underwood, 1995). It is used by the body as an enzyme activator for oxidative phosphorylation and metabolism (McDonals, 1999). Grass in the spring is deficient in magnesium due to the rapid growth of the plant. If the animal is only getting magnesium through the forage, this can leads to hypomagneiumemia in the animal. Magnesium is also involved in nerve impulses and heart beat control and too little magnesium in the blood can lead to sudden death (McDonals, 1999). Clinical symptoms of deprivation include twitching, staring, and lying on the ground with feet churning. An excess will cause rumen skin to degrade, diarrhea, and drowsiness (McDonals, 1999).

Potassium functions in osmotic regulation, acid/base balance and creation of nerve and muscle electrical potential gradients (Underwood, 1995). Deficiencies are rare, but will be severe to the animal. Potassium is found in forages, but a deficiency will show as reduced appetite, poor growth, and paralysis (McDonals, 1999). Excess is also harmful, throwing the acid/base balance off. The acid/base balance is maintained by balancing Na^+, K^+, and CL^- and SO_4^-. If the charges change and cause an overall disruption in pH, the tissues of the animal may be harmed.

Another important mineral is manganese that functions in skeleton and cartilage formation. It also functions in enzyme activity, blood clotting, metabolism, and protection against free oxygen radicals (McDonals, 1999). This mineral is also obtained by eating forages. A deficiency leads to skeleton abnormalities, joint pain, delay of estrus, increased rates of abortions, and ataxia of newborns (Underwood, 1995). In excess, manganese can result in poor growth.

Sodium also functions in maintaining the acid/base balance and nerve impulses (Underwood, 1995). Sodium functions in Na^+ pumps for ATP formation and osmotic pressure (McDonals, 1999). This mineral is only in low amounts in forages and salt licks are often provided to the animals for access to enough sodium. A deficiency is characterized by poor growth, rough hair coat, and dehydration (McDonals, 1999). An excess is characterized much the same way as a deficiency. Chlorine and sodium have many similar functions with chlorine having the additional function of being required to form the gastric secretion of HCl (McDonals, 1999). Deficiency includes eye defects, anorexia, fatigue and increased alkali reserve in the blood (Underwood, 1995). Toxicity is much the same as observed by sodium deficiency.

Aluminum is found in some pastures due to contamination of the soils. Toxicity can result in hypomagnesaemia and reduced phosphorus intake. It is essential, however, to prevent abortions, poor growth, and in coordination (McDonals, 1999). Chronic deficiency can lead to short life spans for the animals.

Neutron Activation

Neutron activation analysis was first theorized in 1936 and by the mid 1940's was considered highly reliable and accurate. It was first employed in the production of semiconductors, but today is widely used in a variety of applications where analysis of elemental concentrations in the parts per million (ppm) or parts per billion (ppb) are required. However, since only elements that produce isotopes can be analyzed, neutron activation analysis is limited to approximately 40 elements. Photon activation analysis can be employed to analyze non-isotropic elements to complete the analysis of the whole mass of the sample.

Advantages of neutron activation analysis over other techniques include: 1) no chemical treatment of sample is needed 2) definite identification of elements in complex compounds 3) extremely high level of precision and accuracy.

The pool type nuclear reactor at The Ohio State University uses ^{235}U. From the list of available isotopes in neutron activation analysis, elements of interest in the caprine study were chosen.

Methods

44 samples were collected from does during their lactation period. Ten does were collected during their lactation one year later. Six does were collected at the start of their lactation and then again, when their babies were weaned. The other does were collected when their babies were weaned. Four types of commercial milk replacer were mixed and tested with different types of water (tap, county, barn and distilled water).

Irradiation of the samples occurred in three reactor runs. Standards with known elemental concentrations were irradiated with the samples. Samples were placed in .1 ml-volume snap-top polyethylene vials and due to the aqueous nature of the samples, they were irradiated by the rabbit method to prevent explosion of the samples in the core of the reactor. Run 1 was irradiated at 350 KW of power for 2 minutes and then 5 minutes. Run 2 was irradiated at 350 KW of power for 4 minutes and then 15 minutes. Run 3 was irradiated at 350 KW of power for 2 minutes and then 15 minutes. Results did not vary between runs since standards were irradiated with each run. The samples were allowed to decay for 2 minutes, 2 hours, several weeks and several months with readings being taken at each interval. This allowed elements with varying half-lives to be counted. A gamma ray spectrometer was used to measure the gamma ray emissions from the isotopes. Energy peaks were counted by a computer program to determine the concentration of elements present. Standards were graphed with their known elemental content and the slope was used to determine the unknown concentrations of the samples in ppm. Results were statistically compared using Statistical Analysis Software to determine if differences in elemental concentrations were statistically significant. P values of less than .05 were considered significant in this study.

Results

Season and goats were compared to see if differences exist from one year to the next or between individual goats. Figure 1 shows that only one element was different between seasons.

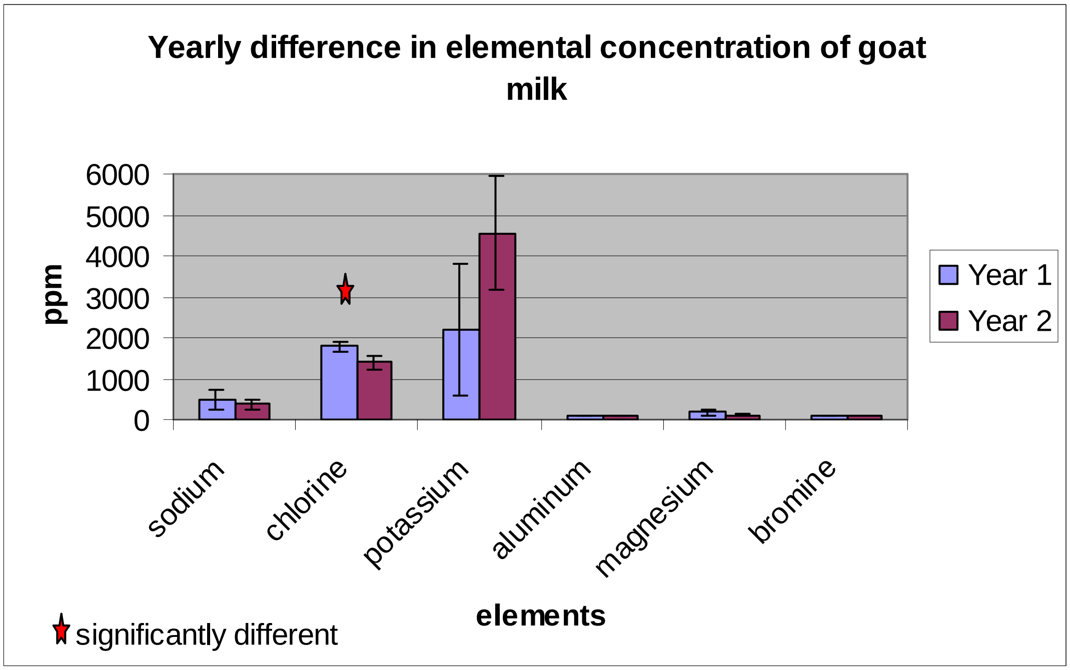

Figure 1: Yearly difference in goat milk

There was a difference in the concentration of chlorine (p=.0428) between seasons. However, there was no difference in the concentration of chlorine between goats (p=.3404). Sodium was not different when comparing between goats, sodium was not different (p=.3752) or between seasons (p=.2215). Potassium also was not different (p=.1600) between goats or between seasons (p=.6809). Aluminum (p=.2263) did not differ between goats or between seasons (p=.4204). Bromine did not differ between goats (p=.6643) or between seasons (p=.2665).

A comparison between early versus late lactation within the same season found that two elements were different.

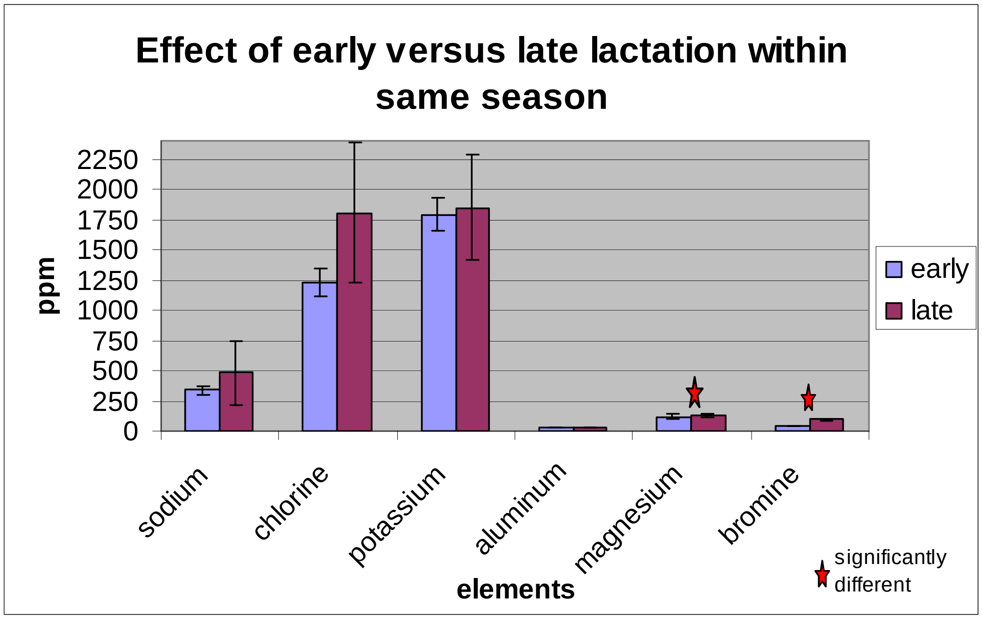

Figure 2: Effect of early and late lactation within the same season

As seen in figure 2 both magnesium (p=.0282) and bromine (p=.0172) were greater in late lactation than in early lactation. However, sodium (p=.3077), chlorine (p= .0722), potassium (p=.2354) and aluminum (p=.1110) did not differ when comparing early versus late lactation.

In the comparison of milk replacers, several elements were found to differ in concentration as seen in figure 3.

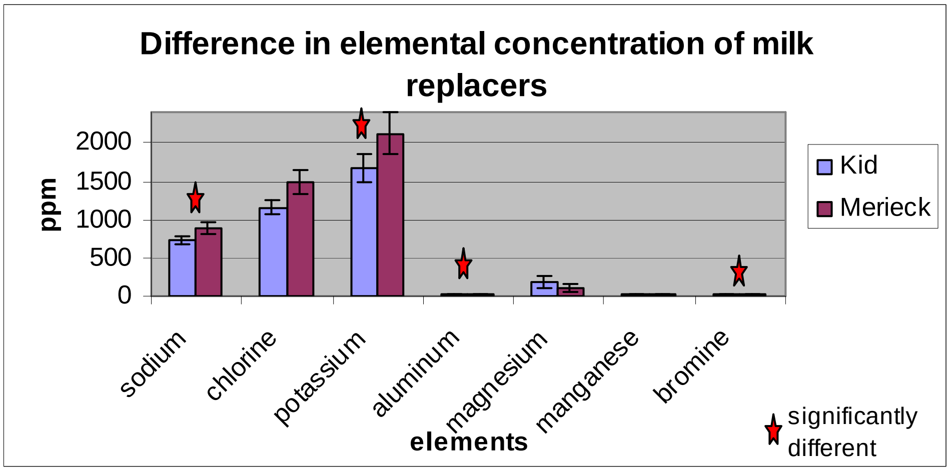

Figure 3: Difference of elemental content of two milk replacers

Sodium concentration was different between the types of milk replacer (p=.0479) with Merieck being higher in concentration. Type of milk replacer (p=.1653) did not differ in chlorine concentration. Merieck was also higher in potassium (p=.0199). Aluminum was likewise different among replacers (p=.0057) with Merieck having a higher concentration. Type of replacer did not have any effect on magnesium (p=.6284). Manganese was found to not be different (p=.1996) between replacers. The type of milk replacer had an effect on the concentration of sodium, potassium, and aluminum. Magnesium, manganese and chlorine did not vary among replacers.

The types of water only had a difference in the elements potassium and aluminum as seen in figure 4.

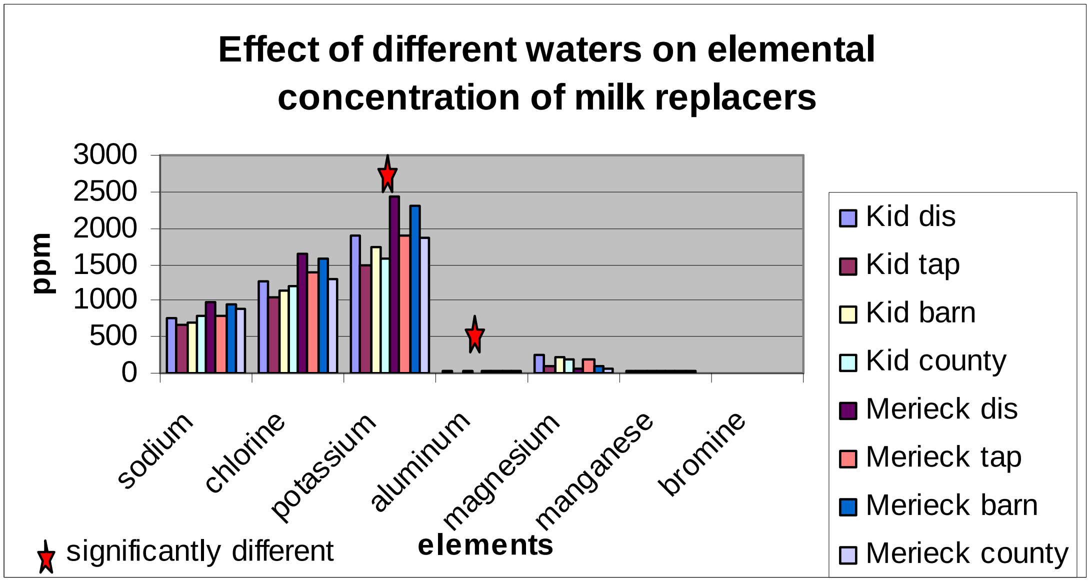

Figure 4: Effect of different waters on milk replacer elemental content

Tap, distilled, barn and county water are all compared to each other in this comparison. Since only potassium and aluminum were the only elements with a difference between waters, a comparison between the types of water was done. Potassium was different in several of the water types including tap to distilled (p=.0064), distilled to barn (p=.0275) and distilled to county (p=.0253). Replacers mixed with distilled water were lower in potassium concentration. It is not different in tap compared to barn (p=.8259), tap to county (p=.7356), or barn to county (p=.9137). Aluminum also had several differences including tap to distilled (p=.0025), tap to barn (p=.0416), distilled to barn (p=.0032), barn to county (p=.0159) but not when comparing tap to county (p=.1328), or distilled to county (p=.0512). Distilled water was lowest in aluminum concentration and the barn water had the highest aluminum concentration.

The effect of all four milk replacers versus goat milk found two elements to be different.

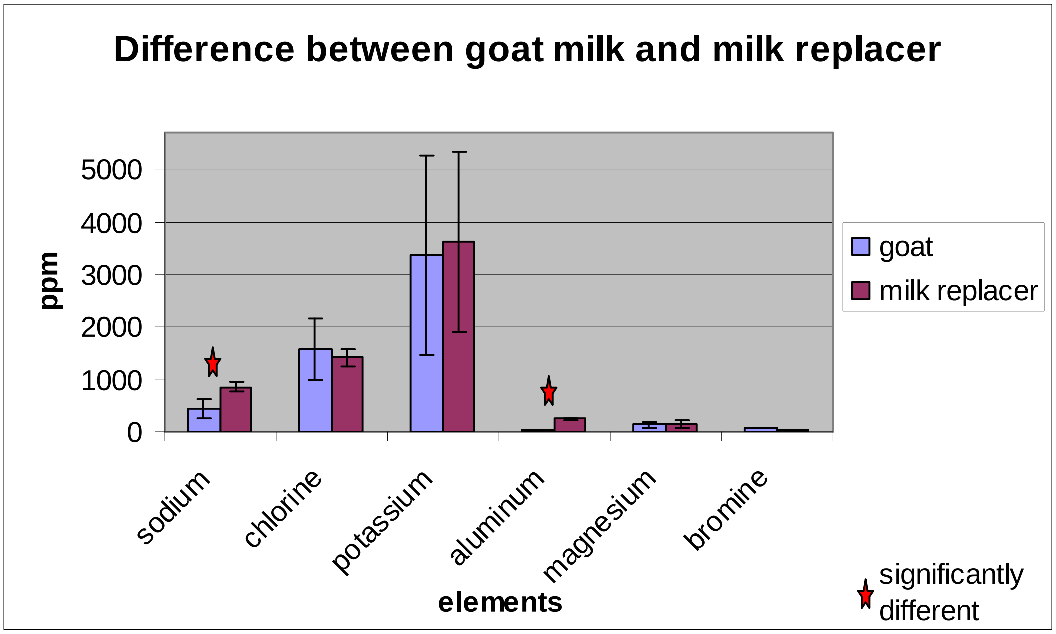

Figure 5: Difference in commercial milk replacer and natural goat milk

As seen in figure 5, sodium (p=.0005) and aluminum (p=.0001) were both much greater in replacers than goat milk. The other elements were not different; chlorine (p=.5590), potassium (p=.1144), magnesium (p=.9039) and bromine (p=.1143).

When comparing all the four milk replacers, it is shown that differences exist between the four companies. Figure 6 summarizes the differences between Kid nutrition, Merieck, Purina, and Sav a kid. For this comparison, statistics could not be used since only one sample was present of each type.

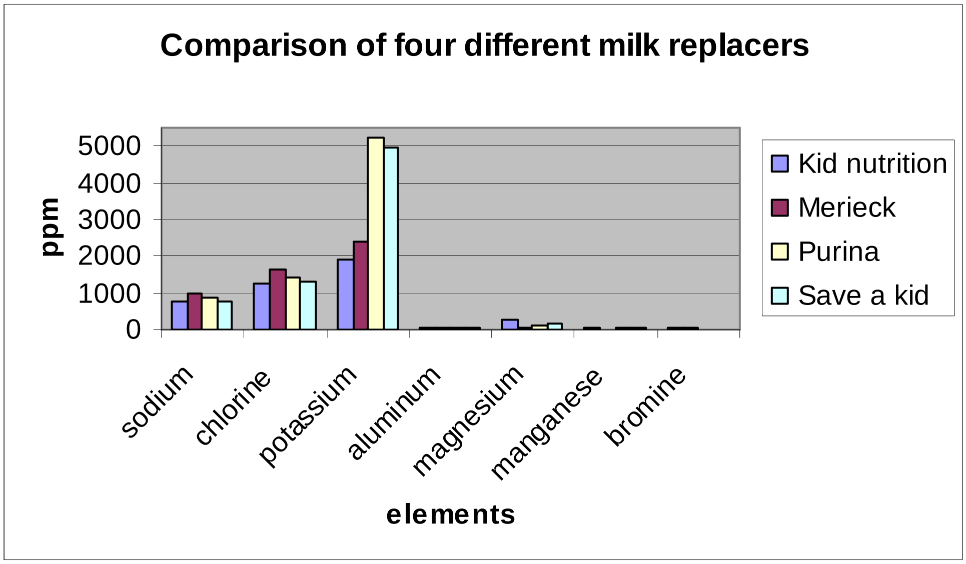

Figure 6: Elemental concentration of the four different milk replacers

Discussion

By using neutron activation analysis, significant differences in the trace element content of natural goat milk and milk replacer can be detected. Environmental aspects in a similarly managed goat flock were shown to not be significant as only chlorine was significantly different from one year to the next. Overall, feed and environmental changes such as weather within the same herd may not substantially affect the elemental content that is in the milk. Between goats, none of the elements tested were significantly different. When considering other effects such as the quality of the udder, number of parities and twinning rate it seems that these elements do not change, as all goats in this study did not have different elemental concentrations.

During the lactation cycle, change in elemental content is expected as nourishment to the young change. Towards the end of the cycle, the young should be consuming external food (pelleted feed and hay) whereas; in the beginning the only nourishment is from the mother's milk. Magnesium and bromine change significantly throughout the cycle. However, sodium, chlorine, potassium and aluminum are not affected by the stage of lactation.

The types of milk replacer used in the study had several significant differences when comparing Kid nutrition and Sav-a-Kid. Sodium, potassium, aluminum and bromine are all elements that differ based upon the company that produces the milk powder. The other elements are all not different in the replacers suggesting very comparable amounts regardless of brand. The types of water may affect the overall elemental content that the young goats are receiving. Elements that were shown to be affected by water are potassium and aluminum. The county water used in this study is treated with 123 ppm of NaCl. The aluminum seems to be the most variable among the several water types with tap and barn water differing even though they are in the same water table. This must be taken into consideration in case the added elemental content of the water could result in toxicity.

Milk replacer and goat milk comparisons attempt to determine how accurately the replacers mimic natural goat milk. Sodium and aluminum are different and may affect the health of the newborn. Aluminum is higher in the replacer and toxicity could negatively affect the mineral balance of phosphorus and magnesium. Sodium is higher in the replacer as well and the result of too much could impact the growth and development of the young.

Many factors work together to determine the health status of the newborn and young goat. Determining the elemental concentrations of several minerals in different scenarios may help determine the best way to maximize infant health. The proper ratios and balances of minerals must be observed to avoid impacting the other minerals. Lactation takes minerals from the adult animal's food sources and secretes them into the milk at the expense of the adult animal. Insuring appropriate mineral supplementation to lactating goats is essential to both mother and baby. Overall, the effect of season and goat is not as variable as stage of lactation, milk replacer and type of water used in the mineral content of these mineral studied. The main objective of this study was to determine if differences exist between the natural goat milk and milk replacers. The results show that there is a difference between sodium and aluminum.

Acknowledgements

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